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ELECTRON BEAM CHARGING AND ARC DISCHARGING OF
SPACECRAFT INSULATING MATERIALS

Semi-Annual Status Report
NASA Grant NSG-7647
Submitted to NASA Lewis Research Center
21000 Brookpark Road, Cleveland, Ohio

March 1983

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Funding agencies:
U.S. Air Force Weapons Laboratory
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1. SUMMARY OF RESEARCH

Samples of Mylar and Teflon film were exposed to combinations of mono-energetic electron and lithium ion fluxes in various ratios. The samples' discharge rates and strengths were found to diminish as the ion proportion increased.

Various types of capacitors were exposed in air to beta irradiation from a 100 mCie Strontium-90 radioisotope source located at distances ranging from 2 cm to 5 cm from the capacitors. In these preliminary experiments, no evidence of spontaneous electrical breakdown was noted, nor was any change in RF impedance detectable using the available instrumentation. A decrease in DC resistance was noted, apparently due to radiation-induced conductivity.

A cylindrical glass vacuum chamber is being assembled. Its inside dimensions are 44 cm diameter by 100 cm length. All necessary associated components and instruments have been acquired, including electron and ion guns, Trek surface potential probe and turbo-molecular pump. A mass-spectrometer detector for leaks and evolved gases will be ordered shortly. All this equipment has been paid for on grants from the Natural Sciences and Engineering Research Council of Canada.

2. PERSONNEL

K.G. Balmain, Principal Investigator.

M. Gossland, Research Engineer.

T. Nozaki, Engineering Technologist.

D.D. Loh, Summer Student (undergraduate).

3. PUBLICATIONS

1. A paper entitled "Incident Ion Effects on Polymer Surface Discharges", by M. Gossland and K.G. Balmain has been submitted for the IEEE Nuclear and Space Radiation Effects Conference, to be held on July 18-21, 1983, at Gatlinburg, Tenn.
2. Two papers have been published in the December 1982 issue of the IEEE Transactions on Nuclear Science. They are: "Optical Measurement of the Velocity of Dielectric Surface Arcs", by K.G. Balmain, M. Gossland, R.D. Reeves and W.G. Kuller, pp.1615-1617; "Barriers to Flashover Discharge Arcs on Teflon", by M. Gossland and K.G. Balmain, pp.1618-1620.
3. The paper "Dielectric Surface Discharges: Effects of Combined Low-Energy and High-Energy Incident Electrons", by K.G. Balmain and W. Hirt, has been accepted conditionally for publication in the IEEE Transactions on Electrical Insulation. This is a slightly augmented version of a paper which appeared in Spacecraft Charging Technology 1980.

4. INCIDENT ION EFFECTS ON POLYMER SURFACE DISCHARGES

4.1 Introduction

The charging by electrons of spacecraft insulating surfaces in synchronous orbit must be accompanied by a contribution from ambient positive ions. Experiments in space (References 1, 2, 3) indicate that proton fluxes are normally less than 1/20 of the electron fluxes, but under charging (eclipse) conditions the relative proportion of protons can rise to 1/10, or sometimes as high as 1/2 in some energy ranges. The laboratory experiments to be described here make use of electron-to-ion current density ratios of 20, 10 and 5 in an attempt to observe ion effects on the properties of the surface arc discharges which result from charge accumulation. The current density magnitudes used in the laboratory experiments are much higher (of the order of 50 times higher) than would be observed in synchronous orbit. However the materials tested (Mylar and Teflon) have been shown (Reference 4) to exhibit discharge properties which are independent of incident electron current density over the relevant range, and so it is reasonable to postulate independence of combined electron and ion current densities provided their ratio remains fixed. Such a postulate can then be tested, using the experimental data to be acquired.

4.2 The Experiment

Two types of dielectric film were used, 75 μm plain Mylar and 125 μm silvered Teflon. Samples were cut from sheet stock, rinsed in trichloroethylene, blown dry, and mounted in the sample holder depicted in Fig. 1. The samples were sandwiched between a copper mask with a 1 cm^2 circular aperture and a copper substrate, each connected separately through a 2.5 ohm

resistor to ground. The current flowing through the substrate resistor during discharge provided a trigger for pen motion on a chart recorder, resulting in a permanent record of discharge occurrences in time.

The electron source was a hot filament followed by a 20 kV accelerator electrode; the beam was magnetically deflected through 90 degrees to permit arc photography. The ion source was an alkali-metal oven intended for application as a surface neutralizer in scanning electron microscopes. This source produces positive lithium ions which have been accelerated through a potential difference of approximately 100 V. Upon close approach to a specimen which has been pre-charged by an electron beam, the ions would be further accelerated.

Each sample was exposed to a constant electron flux for the entire duration of the irradiation sequence. After 5 min of electron exposure (10 min on a few occasions with less responsive samples), the ion beam was turned on at a constant flux for the same interval, then off, then on, then off and finally on again. Thus the only difference between adjacent intervals was the presence or absence of the ion beam.

The electron and ion fluxes quoted in the experiment were defined as those incident on a grounded Faraday cup located behind the mask aperture (see Fig. 1). Because this position was normally occupied by the sample itself, it was unavailable during the tests. Therefore initially the quoted fluxes were calibrated against currents which were available for monitoring during the experiment. The electron flux was calibrated against the current into the side Faraday cup and the ion flux was calibrated against the ion current intercepted by an accelerating grid in the ion source.

For Mylar, the following combinations of fluxes were used: electrons at 100, 50, 25 and 50 nA/cm² with ions at 5, 5, 5 and 10 nA/cm² respectively,

giving electron-to-ion ratios of 20, 10, 5 and 5. For Teflon, the combinations were electrons at 100, 50 and 50 nA/cm² with ions at 5, 5 and 10 nA/cm² respectively, giving the electron-to-ion ratios of 20, 10 and 5.

4.3 Results

The numbers of discharges occurring in each time intervals were expressed as "rates", by dividing them by the time interval itself. Typically these numbers ranged from 3 to 18 per 5-min initial interval (electron exposure), with an average of 7 or 8. The extremes of discharge activity encountered with each combination of material and electron and ion flux are shown in Table 1 which lists the minimum, maximum and average numbers of discharges occurring on a sample during the first time interval. Any samples discharging fewer than three times in this interval were excluded from the results. Aside from fatigue effects and random fluctuations in discharge occurrences, changes in discharge rates from one period to the next were attributed to the ions. Randomness was reduced in the final results by averaging all samples subjected to like conditions. Before averaging, the discharge rates were normalized so that the rates during the first interval were set to unity. This enabled easier comparisons and gave equal weight during averaging to the rates themselves, rather than to the individual discharges.

The normalized discharge rates for three electron-to-ion ratios on Mylar are shown in Figs. 2 to 4. The horizontal plateaus represent the rates and the oblique joining lines enable one to trace the samples' histories. The dots represent the averages of the rates of all of the samples.

In Fig. 2 the electron-to-ion ratio is 20 and no ion effect is visible. The slight overall decline in the average rates demonstrates sample fatigue. In Fig. 3 the ratio is 10 and in addition to fatigue a consistent reduction

in discharge rate upon ion exposure is evident. In Fig. 4 the ratio is 5 and the ion effect is increased.

In Fig. 5, the electron-to-ion ratio is the same as in Fig. 4, but both the electron and ion current densities have been doubled. In Fig. 5 the ion effect is approximately as strong as in Fig. 4, apparently confirming the tentative postulate previously mentioned, that for Mylar the ion reduction in discharge rate depends on the electron-to-ion flux ratio and not on the flux magnitudes.

For Teflon Fig. 6 shows that at an electron-to-ion ratio of 20 produces little or no ion effect; in fact the only effect in evidence is a slight increase in discharge rate with ion exposure. However as the electron-to-ion ratio is reduced to 10 and 5 as shown in Figs. 7 and 8, the ion effect of reduced discharge rate is once more clearly demonstrated. It is worth noting that the results of Fig. 8 for Teflon are similar to those of Fig. 4 for Mylar, the same electron-to-ion ratio having been employed in both experiments.

It should also be noted that the substrate discharge peak currents were somewhat lower in the presence of incident ions; measurements on comparative discharge strengths are continuing.

4.4 Conclusions

The results suggest that low-energy ions when drawn to electron-charged regions on exposed spacecraft dielectrics may serve to reduce both discharge frequency and strength, probably due to near-surface conduction processes.

5. HIGH-ENERGY BETA-IRRADIATION OF CAPACITORS

5.1 Introduction

The objective of the experiments to be described was to explore the effects of high-energy, broad spectrum beta radiation from a 100 mCie Strontium-90 radioisotope on a selection of capacitors. In previous work it was noted that such a source when spaced from 2 cm to 6 cm from a target, provides an approximate simulation of the high-energy part of the synchronous-orbit electron environment, ranging from nuclear-enhanced to natural conditions. In this work, a preliminary search was carried out for three phenomena: electrical breakdown, RF conductivity and DC conductivity.

5.2 Electrical Breakdown

The following capacitor types were tested: Phillips capacitors designated as solid aluminium foil; metallized film (342, 344 series); film foil (347, 352 series); ceramic (type 2); ceramic disk; Micronics capacitors designated as dipped silver mica. The procedure used was to expose the capacitor in air to an estimated 4 pA/cm^2 current density beam from the source which was placed at a distance of 5 cm from the capacitor. The estimated dose rate was of the order of 1 rad/sec. The voltage across the capacitor was monitored by a high-impedance-input JFET type of operational amplifier connected to a chart recorder. The normal voltage across the capacitor changed very slowly with time, so that any sudden change could be readily identified as a possible breakdown.

All the capacitors listed above were tested in this manner for approximately 30 minutes; and no sudden changes in voltage were recorded. The time available did not permit higher dose rates through closer spacing of the

source, nor longer exposure, nor conduct of the experiment in a vacuum. Such additional experiments in vacuum under higher-dose conditions would be necessary to establish clearly whether or not discharges can be caused by the 100 mCie Strontium-90 source.

5.3 RF Conductivity

The experiments were carried out using a Wayne Kerr Model B602 impedance bridge, over the frequency range of 500 kHz to 2 MHz. The bridge measures capacitance and parallel resistance to $\pm 1\%$ accuracy. The capacitors tested were: dipped silver mica (3.29 nF, 63.1 pF, 1.21 nF); film foil (20.9 nF); metallized film (10 nF); ceramic (2500 pF, 0.01 μ F).

Tests were carried out via a coaxial cable connected from the bridge to the capacitor in its exposure cell made of lead bricks lined with Plexiglas. Tests were done by connecting the capacitor directly to the coaxial cable, and also by adding an inductor to permit cancellation of the reactance, thus allowing the bridge to be balanced under a wider range of its internal settings. All tests were carried out with the source located both at 4 cm and at 2 cm from the capacitor. No effect on capacitance or conductance due to irradiation was observed.

5.4 DC Conductivity

In this experiment only the 2500 pF ceramic disk capacitor was tested. The voltage across the capacitor was measured using a high-impedance operational amplifier, and the current through the capacitor was measured using a picoammeter. The radioisotope source was located 4 cm from the capacitor. The operational amplifier had an equivalent circuit consisting of a bias voltage of the order of thirty volts in series with an internal resistance of

the order of 300 GΩ, so that when the capacitor was attached it charged slowly, coming to a steady state in about 15 minutes. At steady state the internal resistance of the capacitor could be deduced from the measured voltage and current.

Before irradiation the resistance of the capacitor was 138 GΩ; during irradiation it fell to 101 GΩ; after irradiation it returned to 127 GΩ. Repetition of the experiment caused the resistance to return always to 127 GΩ, so if indeed there was a slight permanent effect of radiation on the capacitor then certainly this effect was not cumulative.

Calculations based on the literature (see references 5, 6 and 7) and on an estimate of the ceramic capacitor dimensions indicated that the observed radiation-induced conductivity was comparable to typical computed values (within one to two orders of magnitude) for a variety of insulating materials, although figures for ceramics were not available. Therefore it is reasonable to ascribe the effect observed as due to radiation-induced DC conductivity.

5.5 Conclusions

Under the specific experimental conditions of exposure of various capacitors in air to a Strontium-90 radioisotope source, no electrical breakdown was observed and no change in RF impedance was detectable. For a ceramic disk capacitor, a 37% increase in DC conductivity was observed, the change having been identified with reasonable certainty as radiation-induced conductivity.

The phenomena searched for in these preliminary tests appear to be either non-existent or weak. Nevertheless it would still be reasonable to repeat the breakdown search and the DC conductivity measurements in vacuum, using higher dose rates and longer exposures. In particular, the breakdown

tests should be done with the capacitor at its maximum normal operating voltage.

6. REFERENCES

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2. J.B. Reagan et al, Spacecraft Charging Technology 1980, NASA CP 2182/AFGL-TR-81-0270, pp.74-85.
3. J. Wilkenfeld et al, RADC-TR-81-198, July 1981.
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5. B. Gross, M.G. Sessler, and J.E. West, J. Appl. Phys., Vol. 45, No. 7, pp.2841-2851, 1974.
6. B. Gross, J.E. West, H. von Seggern, and D.A. Berkley, J. Appl. Phys., Vol. 51, No. 9, pp.4875-4881, 1980.
7. R.D. Reeves and K.G. Balmain, IEEE Trans. Nucl. Sci., Vol. NS-28, No. 6, pp.4547-4552, 1981.

Table 1

SUMMARY OF INITIAL DISCHARGE RATES

<u>Figure</u>	<u>Material</u>	<u>Electron Flux (nA/cm²)</u>	<u>Ion Flux (nA/cm²)</u>	<u>Number of discharges on a sample during first interval (prior to to ion exposure)</u>		
				<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>
2	Mylar	100	5	6	12	9
3	Mylar	50	5	3	16	9
4	Mylar	25	5	3	10	6
5	Mylar	50	10	3	7	5
6	Teflon	100	5	6	18	7
7	Teflon	50	5	3	13	8
8	Teflon	50	10	4	12	8

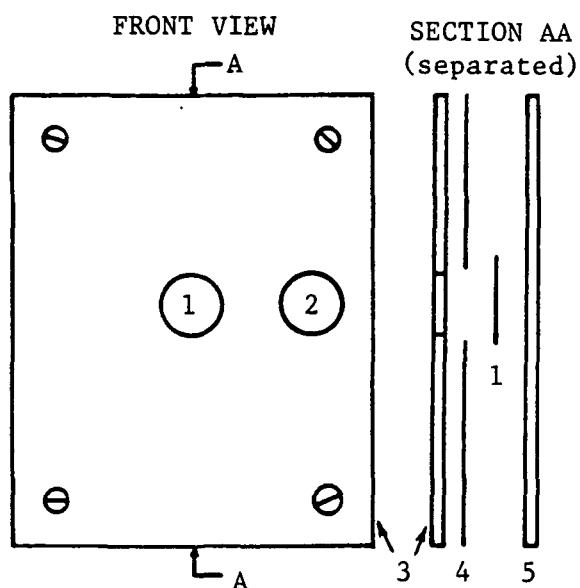


Fig. 1
1-Sample, 2-Faraday Cup,
3-Mask, 4-Insulator,
5-Substrate.
During calibration, a
Faraday cup was behind
the mask aperture (1)
and the substrate was
absent.

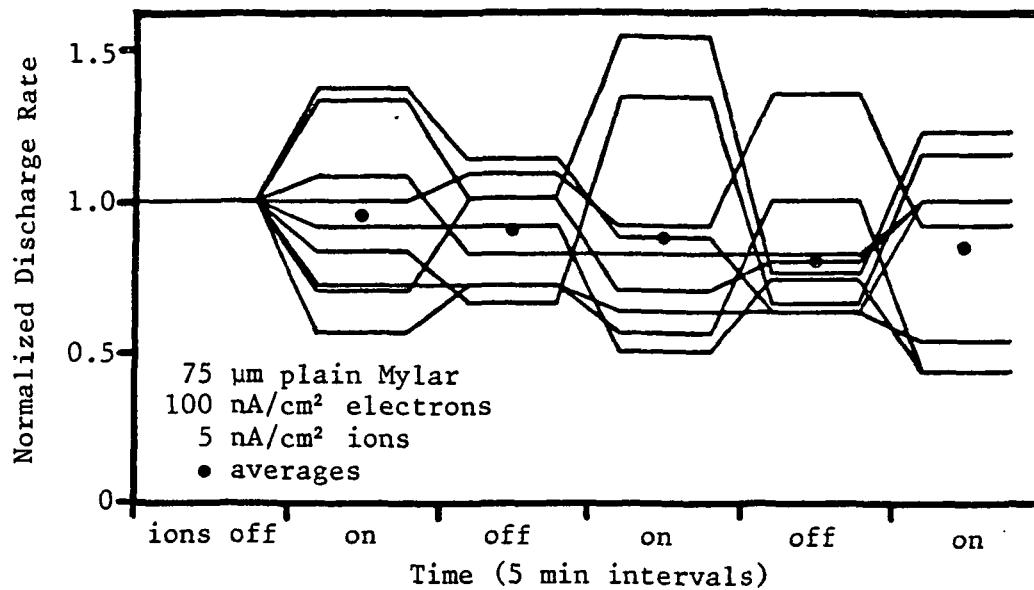


Fig. 2 Normalized discharge rates for Mylar with an electron-to-ion flux ratio of 20.

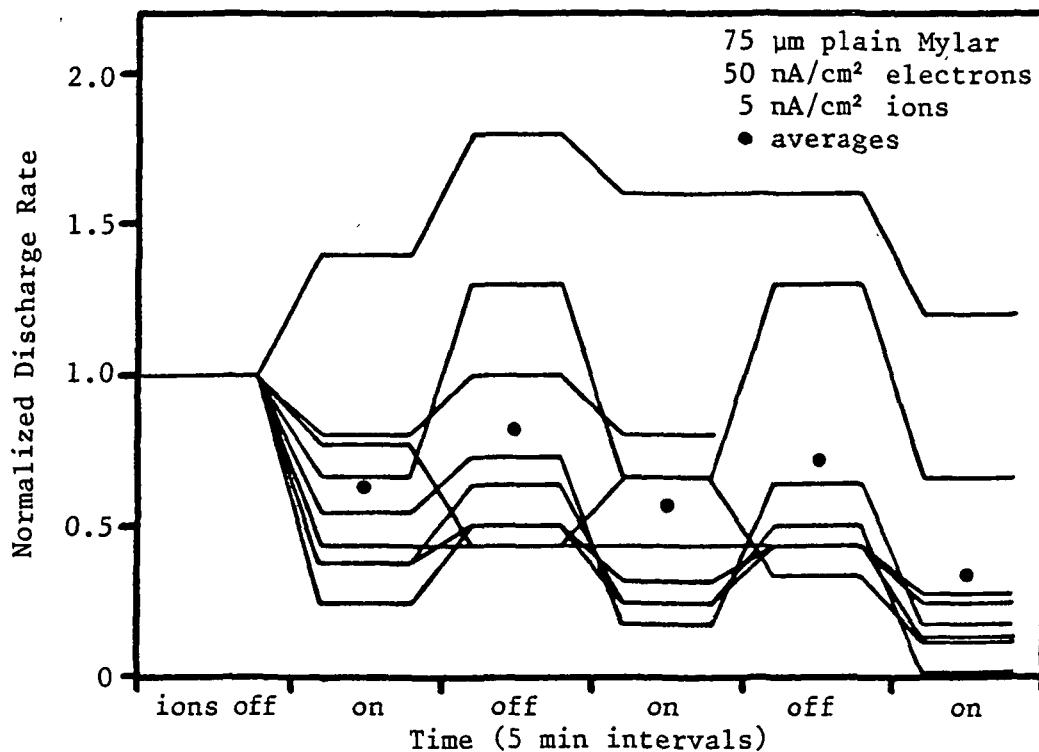


Fig. 3 Normalized discharge rates for Mylar with an electron-to-ion flux ratio of 10.

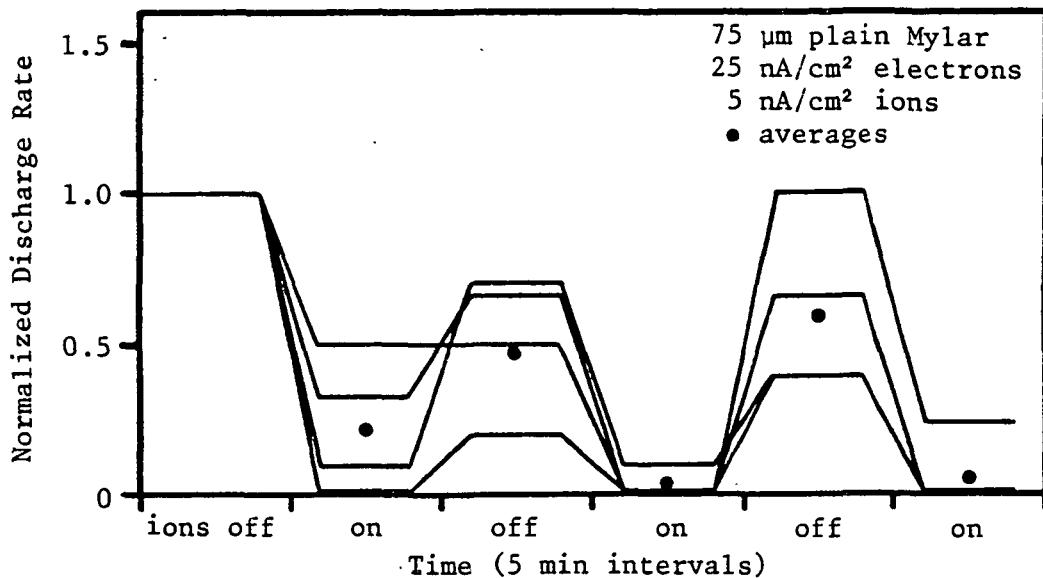


Fig. 4 Normalized discharge rates for Mylar with an electron-to-ion flux ratio of 5.

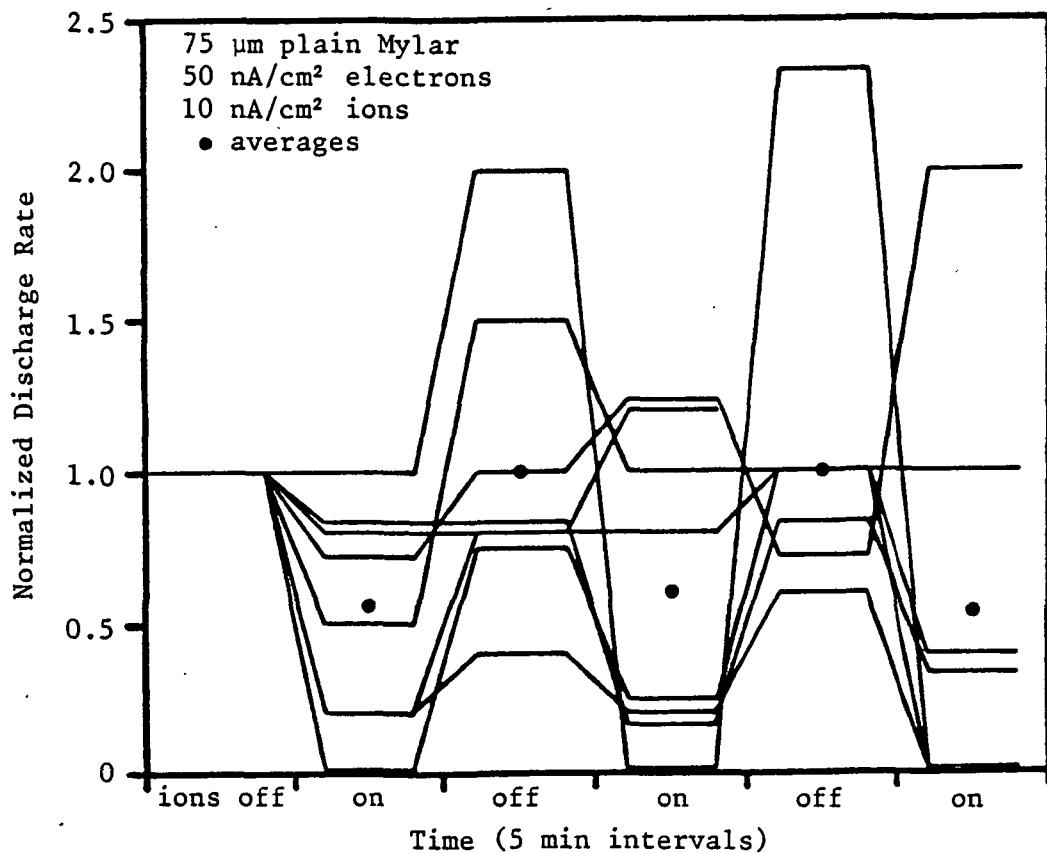


Fig. 5 Same as Fig. 4 but both currents increased by a factor of 2.

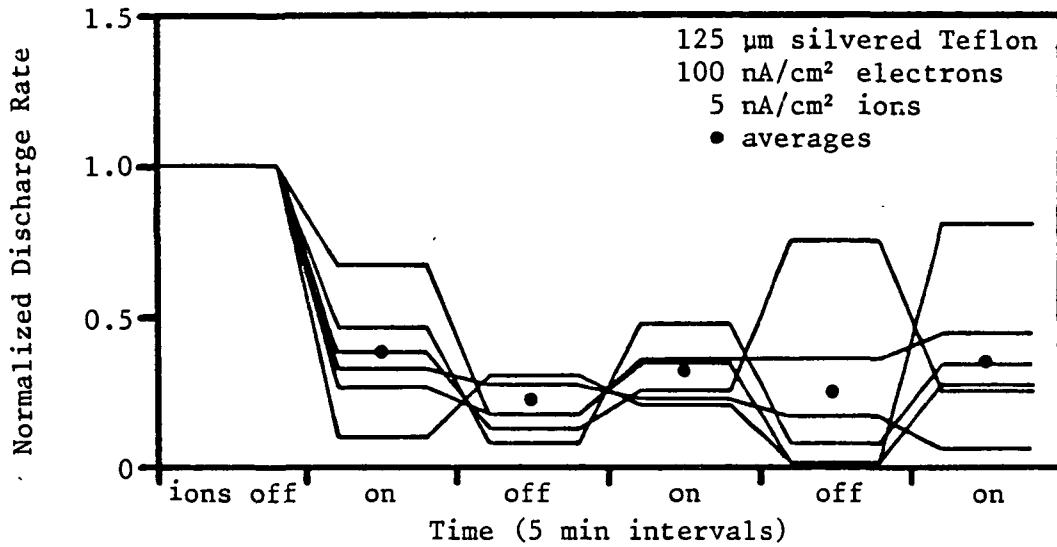


Fig. 6 Normalized discharge rates for Teflon with an electron-to-ion flux ratio of 20.

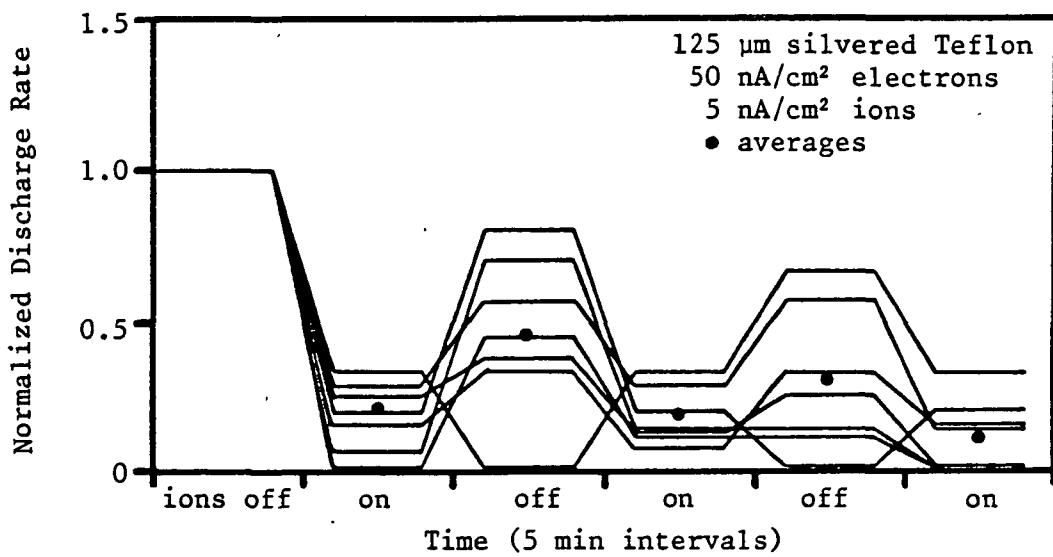


Fig. 7 Normalized discharge rates for Teflon with an electron-to-ion flux ratio of 10.

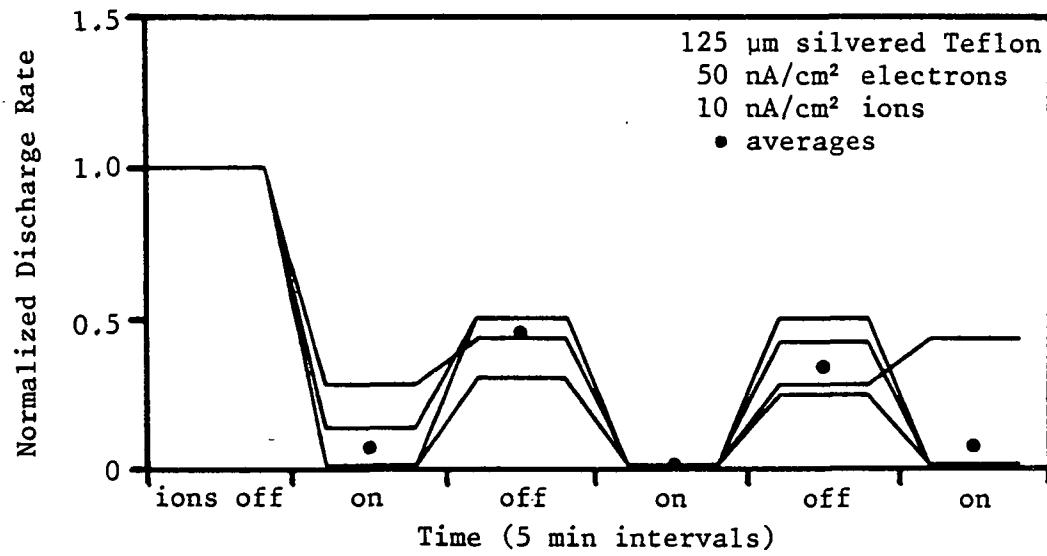


Fig. 8 Normalized discharge rates for Teflon with an electron-to-ion flux ratio of 5.